



Technology Readiness Assessment of a Large DOE Waste Processing Facility

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**Don Alexander, DOE/ORP
Langdon Holton, PNNL
Herb Sutter, Consultant**

Office of River Protection
Department of Energy
Richland, Washington

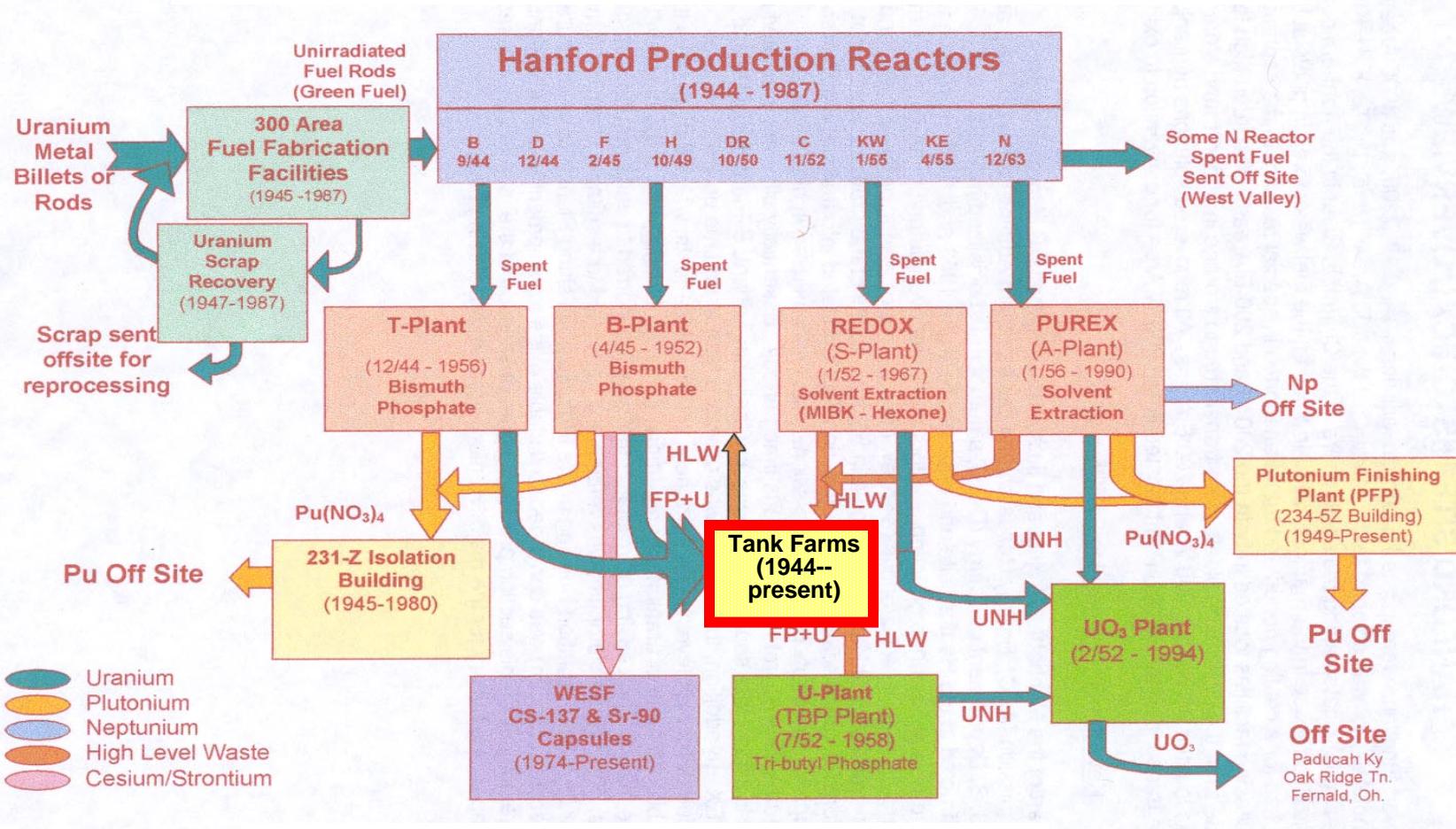
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Outline

- Background
 - Waste Generation at Hanford
 - Waste Treatment and Immobilization Plant (WTP) Project
- Motivation to Conduct TRA
- TRA Approach
- Actions to ensure consistency with DoD TRA's
- Observations from TRA/TMP Process
- Next Steps

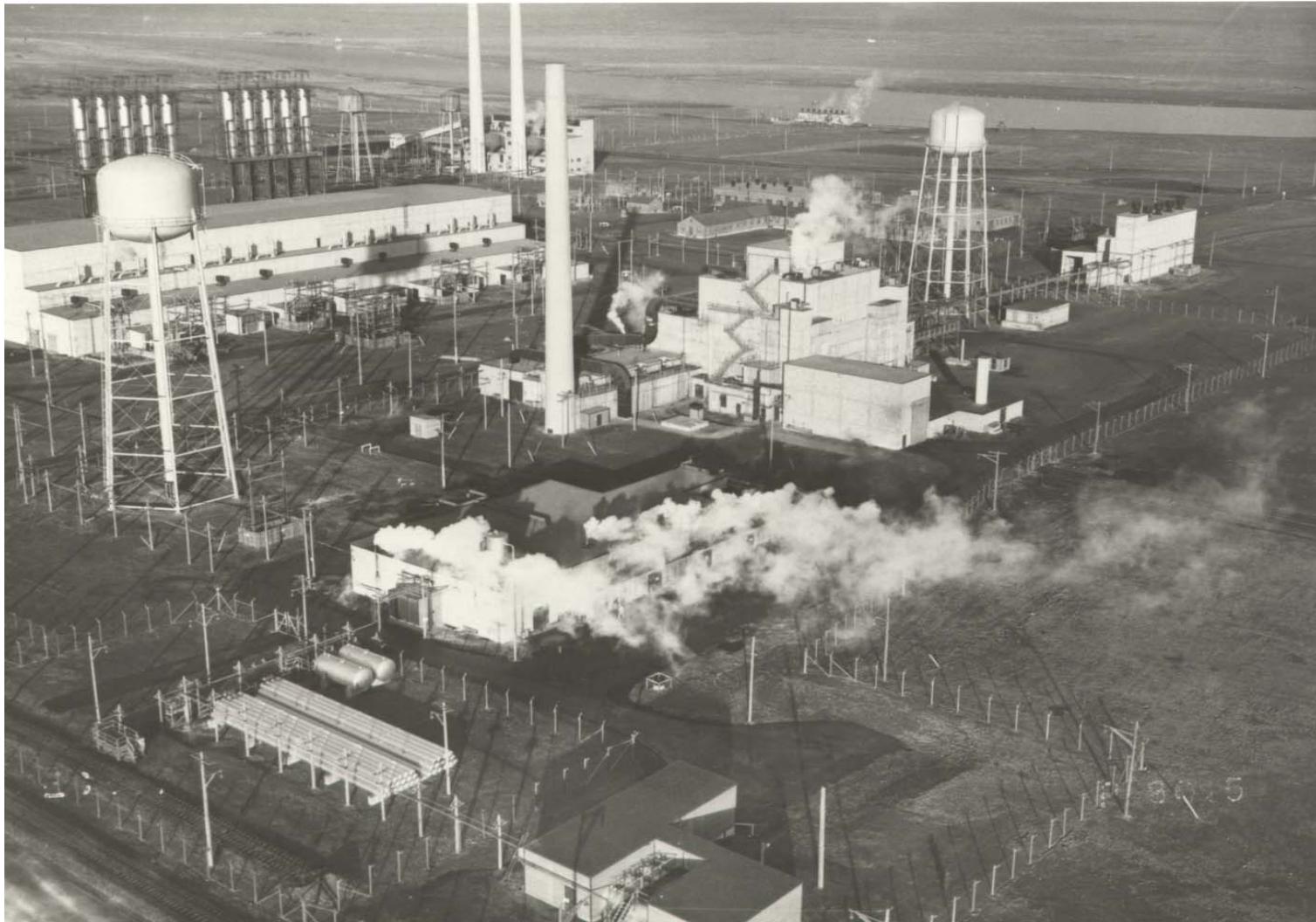
Generation of Hanford Tank Wastes



9 Reactors; 4 Fuel Reprocessing Flowsheets; 100,000 MT Fuel Processed 3



Hanford's B Reactor, as it stood in 1945





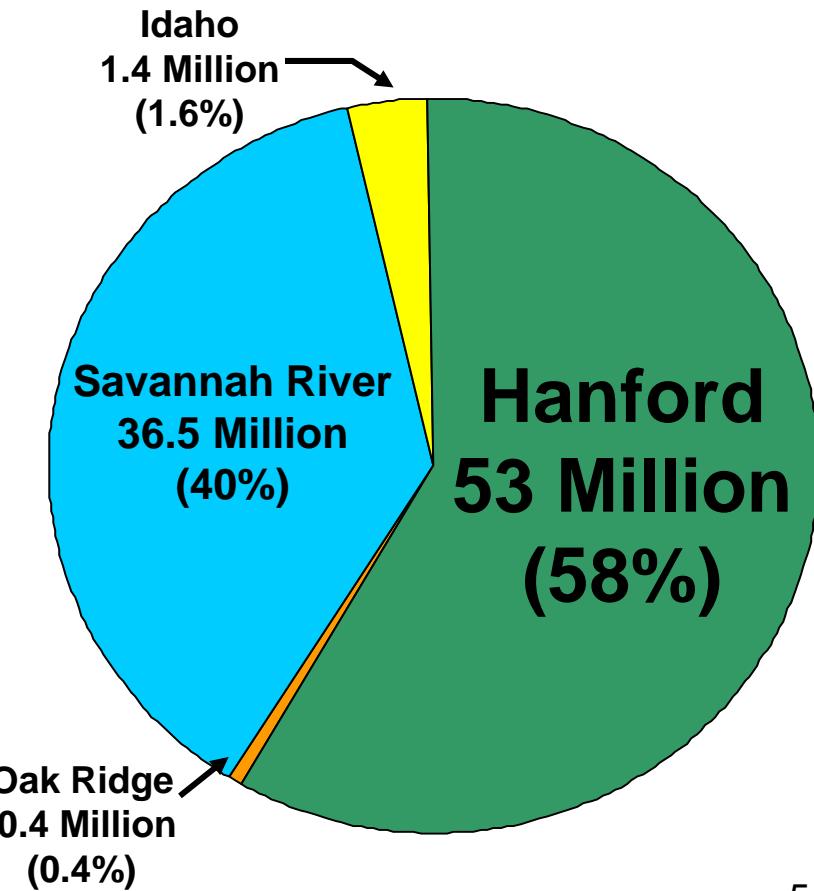
Hanford Tank Waste Cleanup Challenge



Hanford has:

- 63% of DOE tanks; 80% of DOE single-shell tanks
- 58% of DOE total tank waste
- ~194 million curies of radioactivity
- ~190,000 tons of chemicals

Total Number of Gallons in Waste Tanks at DOE Sites:





Single Shell Tanks (SSTs) under Construction



149 SSTs
Capacity up to 1 Mgal

P 6885



Double-Shell Tanks (DSTs) under Construction



28 DSTs
Capacity 1 Mgal
Diameter 80 ft
Height 49 ft





Waste Treatment Plant (WTP)

Hanford's WTP will be the world's largest radioactive waste treatment plant to treat Hanford's underground tank waste

Major Facilities

1. Pretreatment (PT) Facility
2. Low Activity Waste (LAW) Vitrification Facility
3. High Level Waste (HLW) Vitrification Facility
4. Analytical Laboratory
5. Balance of Facilities

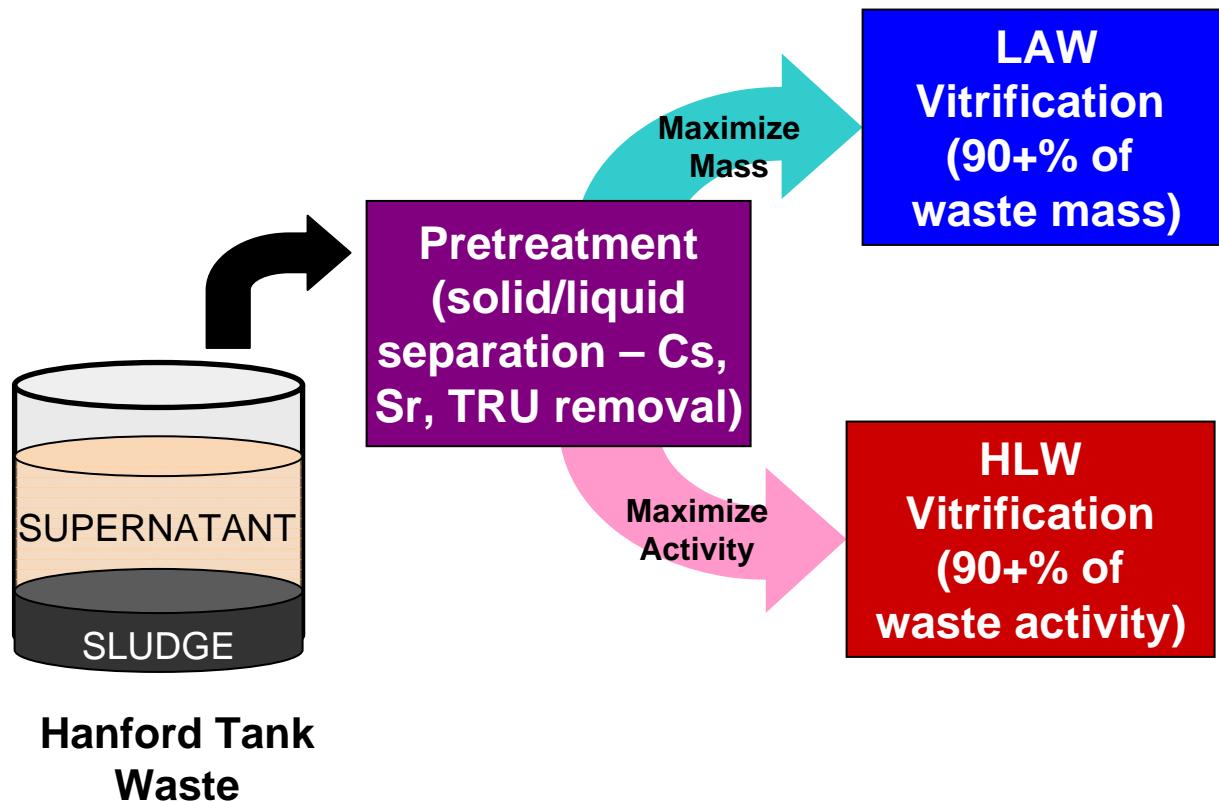
Commodities

Concrete	90,000 CY
Structural Steel	10,000 Ton
Pipe	160,000 ft
HVAC	1,200 Ton
Cable Tray	40,000 ft
Conduit	220,000 ft





WTP Flow Sheet – Key Process Flows





How is the Vitrified Waste Dispositioned?

High Level Waste Canisters

- 2' x 14.5'
- 6,600 pounds of glass
- 600 canisters to be produced/year
- Temporarily stored in Hanford's Canister Storage Building until National Repository opened



Low Activity Waste Containers

- 4' x 7.5'
- 13,000 pounds of glass
- 1,300 containers to be produced/year
- Disposed on Hanford Site



Aerial View of the Waste Treatment Plant

\$12.2 B 2019 Completion



Project 38% complete

~2650 staff



Pretreatment Facility - July 2007



**Pretreatment Facility
Design 70% Complete
Construction 25% Complete**

**5 Stories (0', 28', 56', 77', 98')
250' Wide x 558' Long + 28' wide loading bay/dock
119' Tall (Top of Basemat at Grade to Roof)**



Feed Receipt Vessels in Fabrication-2004

Feed Receipt Vessels (4)

- Largest Vessels in Pretreatment
- Batch Volume 375,000 gal
- Diameter 47 ft, Height 43 feet





Feed Receipt Vessel being lifted into Shielded cell

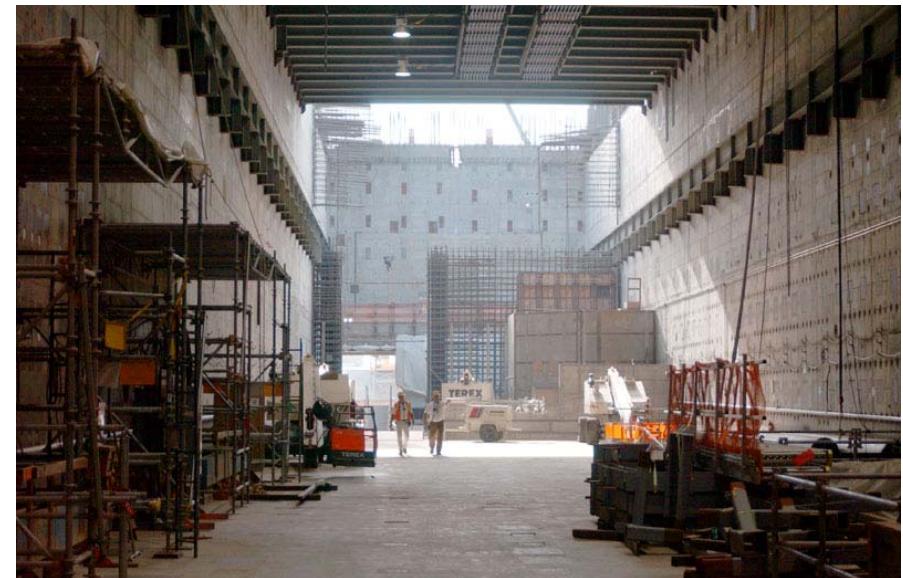




Pretreatment Black Cell and Hot Cell



- **Permanent equipment installed in Black Cell**
 - 15 Black Cells
- **Equipment requiring maintenance installed in Hot Cell- maintainable/replaceable area**
- **Design concept allows insertion of new/modified technologies at later date**





HLW Vitrification



HLW Vitrification Facility
Design 79% Complete
Construction 20% Complete

4 Stories (0', 14', 37', 58')
281' Wide x 448' Long
120' Tall (Bottom of Basemat @ -21' to Roof)



LAW Vitrification



LAW Vitrification Facility
Design 93% Complete
Construction 48% Complete



Analytical Laboratory



Analytical Laboratory
Design 88% Complete
Construction 35% Complete



Background for WTP TRAs

- **GAO initiated review of DOE projects in 2006 to assess relationship between technology maturity and project cost growth and schedule extension**
 - 12 DOE projects reviewed-WTP included
 - Concluded that implementing immature technology in design was part of the reason for cost growth
 - Recommended that DOE use a consistent process for measuring readiness of critical technologies
 - DOE supports GAO's recommendation and suggested a pilot application to understand process
- **In late 2006 DOE initiated 3 Technology Readiness Assessments for WTP**

GAO <small>March 2007</small>	<p style="text-align: right;"><small>United States Government Accountability Office</small></p> <p>Report to the Subcommittee on Energy and Water Development, and Related Agencies, Committee on Appropriations, House of Representatives</p> <p style="text-align: right;">DEPARTMENT OF ENERGY</p> <p style="text-align: right;">Major Construction Projects Need a Consistent Approach for Assessing Technology Readiness to Help Avoid Cost Increases and Delays</p> <p style="text-align: right;"> GAO <small>Accountability • Integrity • Reliability</small></p>
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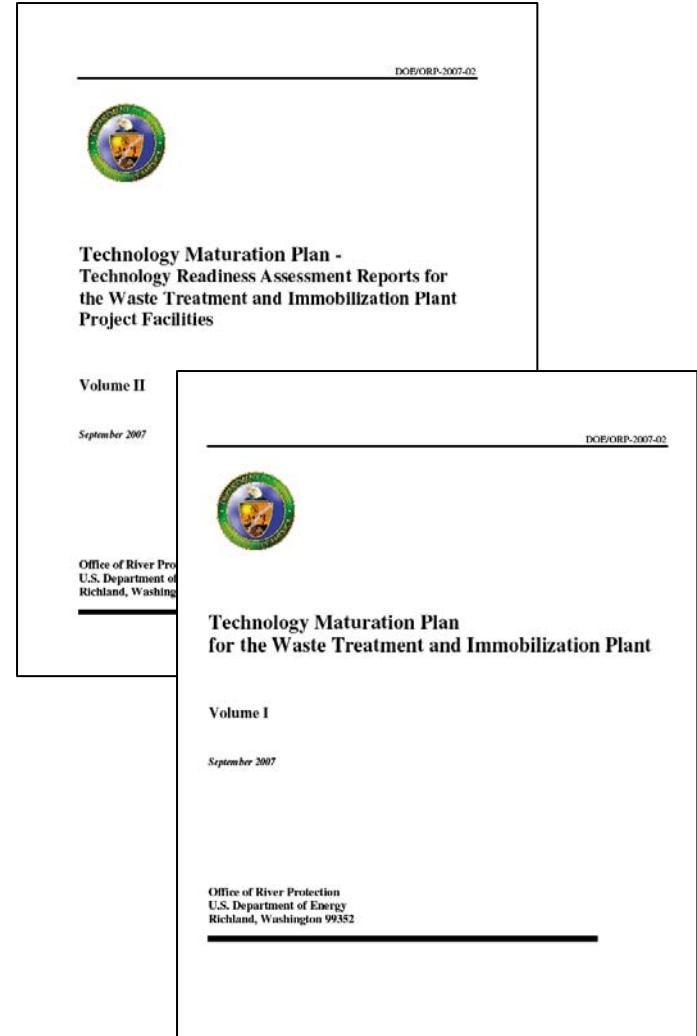


WTP TRAs Status

Three TRA's Completed for WTP

- *Technology Readiness Assessment for the Waste Treatment and Immobilization Plant (WTP) Analytical Laboratory, Balance of Facilities and LAW Waste Vitrification Facilities, 07-DESIGN-042, U.S. Department of Energy, Richland, Washington*
- *Technology Readiness Assessment for the Waste Treatment and Immobilization Plant (WTP) HLW Waste Vitrification Facility, 07-DESIGN-046, U.S. Department of Energy, Richland, Washington*
- *Technology Readiness Assessment for the Waste Treatment and Immobilization Plant (WTP) Pretreatment Facility, 07-DESIGN-047, U.S. Department of Energy, Richland, Washington*

Technology Maturation Plan Completed





Purpose of the WTP TRAs

- Assess the maturity of Critical Technology Elements to:
 - Determine readiness of proceeding/continuing with design and construction
 - Identify immature technologies and components (for tracking of maturity of development)
 - Identify technology development needs for immature technologies
- Apply and refine TRL process for potential use by EM Design/Construct Projects



Methodology for Completion of TRAs

TRAs based upon method described in
Department of Defense, Technology Readiness Assessment (TRA) Handbook, May 2005

Steps in TRA

1. Identification of Critical Technology Elements (CTEs)
2. Completion of TRL Assessment for each CTE
3. Completion of Technology Maturation Plan for technologies with TRL less than 6



WTP TRA Approach (1)

1. Critical Technology Element determination completed in 2 steps
 - Candidate CTE's identified by Assessment Team (DOE/Independent Contractor)
 - Final determination made with WTP Contractor support using DoD criteria
2. Revision of TRL Level definitions for Radiochemical Processing
 - Comparison of NASA, DoD and DOE-EM scale prepared
3. TRLs determined using modified "Nolte" calculator (Level 1-6)
 - All criteria to be met to complete level
 - Software systems not evaluated



WTP TRA Approach (2)

4. Process involved due-diligence prior to, during, and following TRL scoring
 - Treated criteria scoring as a “finding of fact”
 - WTP Contractor involving in initial scoring
 - Final scoring done following additional due diligence by Assessment Team
5. TRA Report provided to WTP Contractor for factual accuracy review.
6. Technology Maturation Plan prepared for CTEs < 6



Technology Readiness Level Scale-Summary Level

System Operations	TRL 9	Actual equipment/process successfully operated in the operational environment (Hot Operations)
System Commissioning	TRL 8	Actual equipment/process successfully operated in a limited operational environment (Hot Commissioning)
	TRL 7	Actual equipment system/process system successfully operated in the expected operational environment (Cold Commissioning)
Technology Demonstration	TRL 6	<i>Prototypical equipment/process system demonstrated in a relevant environment (Cold Engineering Scale Pilot Plant)</i>
Technology Development	TRL 5	Bench scale equipment/process system demonstrated in a relevant environment
	TRL 4	Laboratory testing of similar equipment systems completed in a simulated environment.
Research to Prove Feasibility	TRL 3	Equipment and Process analysis and proof of concept demonstrated in a simulated environment
	TRL 2	Equipment and process concept formulated
Basic Technology Research	TRL 1	Basic process technology principles observed and reported

TRL 6 normally required for incorporation of technology into design



Technical Readiness Assessment Summary

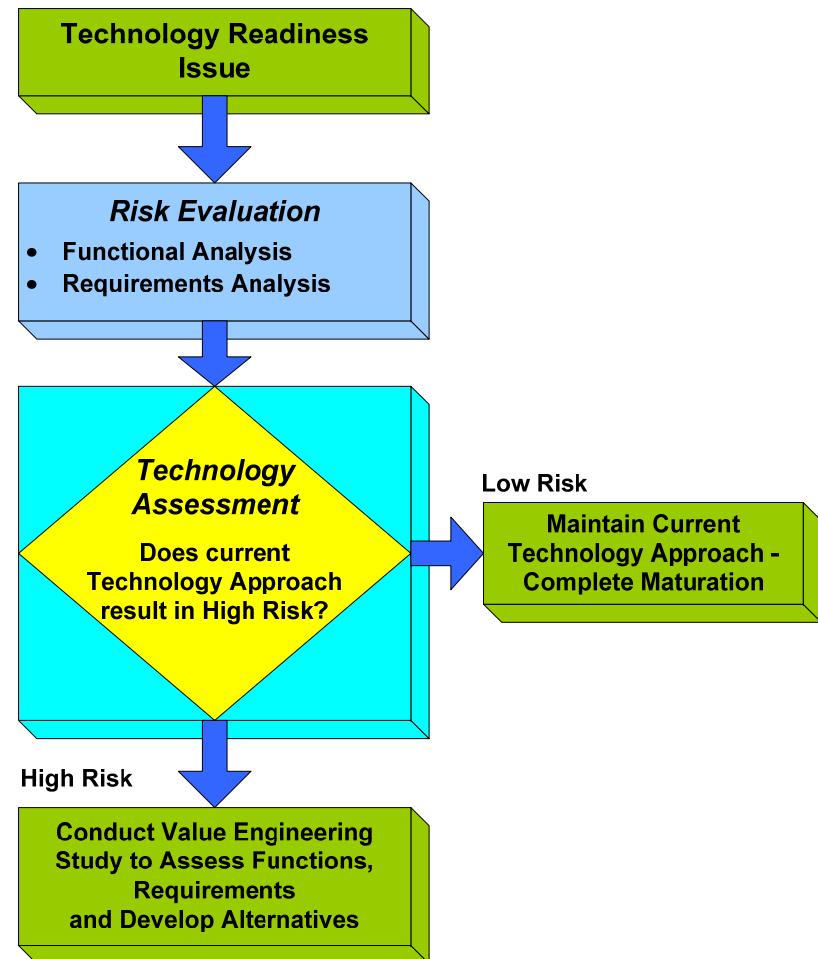
Facility	Number of Systems considered in TRA as Potential CTEs	Number of CTEs selected for Detailed Maturity Assessment	Number of CTEs with a Technology Maturity Level less than 6
Pretreatment	33	9	9
Analytical Laboratory	20	1	1
Balance of Facilities/WTP Common	70	1	0
LAW Vitrification	33	5	2
HLW Vitrification	30	5	2
Total	186	21	14 (8 ^a)

^a Common mixing issues were identified for the following systems: Cesium Ion Exchange Process System (CXP), Waste Feed Evaporation Process System (FEP), Waste Feed Receipt Process System (FRP), HLW Melter Offgas Treatment Process System (HOP), HLW Lag Storage and Feed Blending Process System (HLP), Treated LAW Evaporation Process System (TLP), and Plant Wash and Disposal System (PWD)/Radioactive Liquid Waste Disposal System (RLD).



Development of Technology Maturation Plan

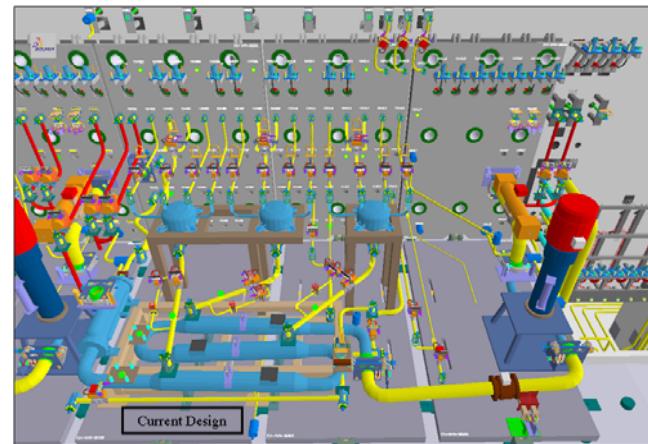
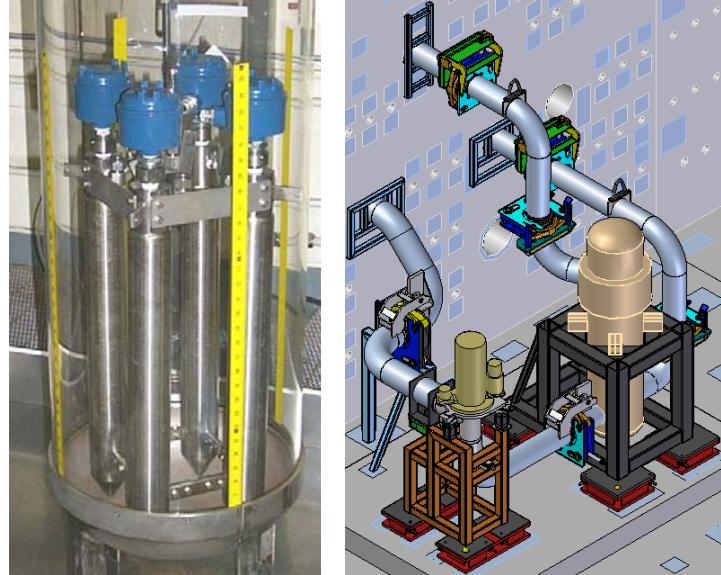
- CTE's < 6 were subjected to risk assessment to determine impact if not matured
- CTEs with significant consequence required technology maturation plans
- CTE < 4 required identification of alternative technology
- Principles of Systems Engineering and Value Engineering used in Development of Maturation Plan
 - Reassessment of Requirements
 - Reassessment of Functions





WTP Systems Requiring Maturation

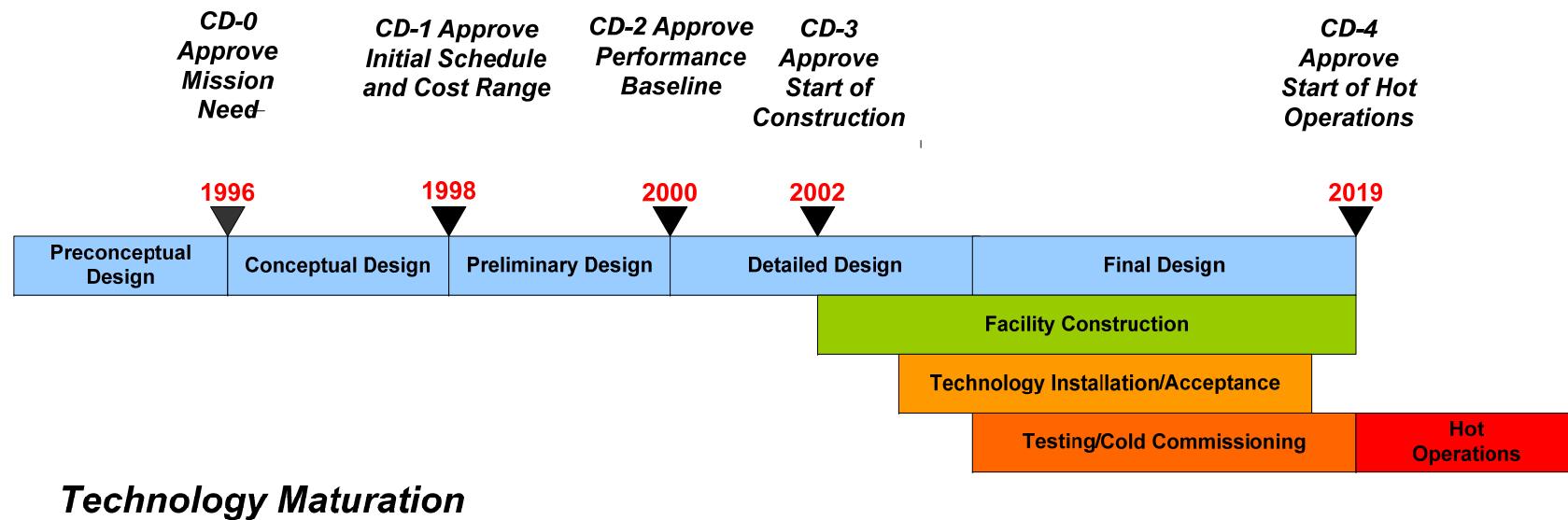
- Pulse Jet Mixing
- Waste Solids Separation
- Radioactive Cesium Removal
- Nitric Acid Recovery and Recycle
- Laser Ablation-Inductivity Coupled Plasma-Atomic Emission Spectrometer
- HLW Melter Offgas Treatment (Electrostatic Precipitator)
- LAW Container Sealing
- LAW Container Decontamination





Technology Maturation Sequence and WTP Critical Decisions

DOE's Project Management Process as Applied to WTP



WTP Design Build Approach allows Technology Maturation at later stage in Project



Alignment of DOE Critical Decision Milestones with TRLs

- WTP design concept is flexible and supports technology insertion (new/modified technology) after start of Construction
- Small number of CTEs rated less than TRL 6
 - 186 potential CTEs were identified
 - 21 CTEs were selected for detailed evaluation
 - 14 of 186 CTEs were rated less than TRL 6 (7.5%)
 - Mixing issues were combined resulting in 8 CTEs for maturation
- Cost of WTP delay would exceed cost risk of maturation
 - Maturity schedule will be managed within the current construction schedule



Actions to Ensure Consistency with DoD TRA Process

- DoD TRA Deskbook used as guide
- NASA/DoD TRL definitions used with minor modification
 - Adapted to waste treatment
- Consultation with Bill Nolte of the Air Force Research Laboratory (AFRL)
 - Participated with DOE Assessment Team in initial TRA
 - Supported modification and use of AFRL TRL Calculator (originated by Nolte) to ensure consistency with NASA/DoD scoring
- Independent review of WTP Technology Maturation Plan by Nolte (AFRL) and Bilbro (NASA Technology-retired)



Observations on TRA Process

- DoD TRA provides structured, objective and clearly documented process
 - Helps identify specific actions needed to reduce programmatic risk
 - Complements DOE Design Oversight Process
- TRAs are a “finding of fact”.
 - Specified criteria (e.g. “Nolte Calculator”) essential to ensure consistency in assessments
- TRL Levels usually higher when strong technology program is completed, e.g. “make technology”.
 - Choices to “buy technology” or “engineer technology” without testing have led to lower TRLs.
- “Relevant Environment” and “Prototypic Testing” are critical concepts in TRA.
 - Practical difficulties and limitations of large scale testing with actual wastes with increased cost, complexity and risk may outweigh its value
 - Project design must mature with technology to ensure that testing is relevant.



Next Steps Planned for WTP

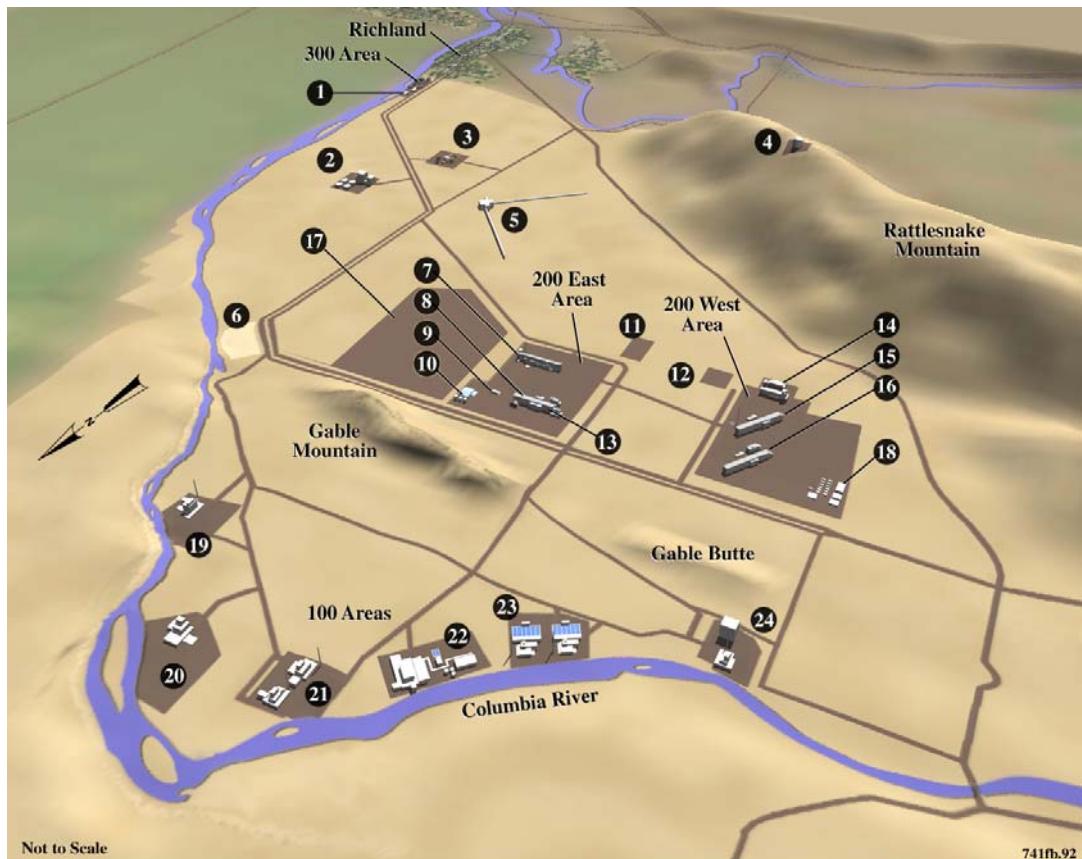
- Assess Readiness of WTP Software Systems
- Modify “Nolte Calculator” to support assessment of Readiness for Cold/Hot Commissioning (TRL Level 7/8)



Backup



Hanford Cleanup Site



1. 300 Area Liquid Effluent Treatment Facility
2. Commercial Operating Nuclear Power Plant
3. Fast Flux Test Facility
4. Observatory
5. Laser Interferometer Gravitational Wave Observatory
6. Old Hanford Town Site
7. Plutonium Uranium Extraction Plant
8. B Plant
9. Prototype Engineered Barrier
10. 200 East Area Effluent Treatment Facility
11. U.S. Ecology Commercial Solid Waste Site
12. Environmental Restoration and Storage Facility
13. Waste Encapsulation and Storage Facility
14. REDOX
15. U Plant
16. T Plant
17. Waste Treatment Plant
18. Waste Receiving and Processing Facility
19. F Reactor
20. H Reactor
21. D and DR Reactors
22. N Reactor
23. KE and KW Reactors
24. B and C Reactors



Balance of Facilities





Determination of Critical Technology Elements (CTEs)

- CTE assessment completed for all WTP Process and Process Support Systems for each facility
- CTEs determined by response to two sets of questions
- Must have positive response to at least one question in each question set for determination as CTE
- CTE's to be evaluated with Technology Readiness Levels

First Question Set

- Does the technology directly impact a functional requirement of the process or facility?
- Do limitations in the understanding of the technology result in a potential schedule risk, i.e., the technology may not be ready for insertion when required?
- Do limitations in the understanding of the technology result in a potential cost risk, i.e., the technology may cause significant cost overruns ?
- Are there uncertainties in the definition of the end state requirements for this technology ?

Second Question Set

- Is the Technology New or Novel?
- Is the Technology modified?
- Has the technology been repackaged so a new relevant environment is realized?
- Is the technology expected to operate in an environment and/or achieve performance beyond its original design intention or demonstrated capability?



TRL Requirements and Definitions

Scale

Full Plant Scale

Matches final application

Engineering Scale

Typical ($1/10 < \text{system} < \text{Full Scale}$)

Laboratory/Bench Scale

$< 1/10 \text{ Full Scale}$

System Fidelity

Identical System Configuration

- matches final application in all respects

Similar System Configuration

- matches final application in almost all respects

Pieces - System matches a piece or pieces of the final application

Paper - System exists on paper - no hardware system

Environment (Waste)

Operational (Full Range)

Full range of actual waste

Operational (Limited Range)

Limited range of Actual waste

Relevant

Simulants + a limited range of actual wastes

Simulated

Range of simulants



Testing Requirements for TRLs

TRL Level	Scale of Testing	Fidelity	Environment
9	Full	Identical	Operational (Full Range)
8	Full	Identical	Operational (Limited Range)
7	Full	Similar	Relevant
6	Engineering/Pilot Scale	Similar	Relevant
5	Lab/Bench	Similar	Relevant
4	Lab	Pieces	Simulated
3	Lab	Pieces	Simulated
2		Paper	
1		Paper	



TRL Calculator Key

- H-Hardware element, contains no appreciable amount of software
- S-Completely a Software system
- B-Some Hardware and Software
- T-Technology, technical aspects
- M-Manufacturing and quality
- P Programmatic, customer focus, documentation



TRL Calculator-Top Level View Questions

TOP LEVEL VIEW -- Demonstration Environment (Start at top and pick the first correct answer)	
<input type="radio"/>	Has the actual equipment/process successfully operated in the full operational environment (Hot Operations)?
<input type="radio"/>	Has the actual equipment/process successfully operated in a limited operational environment (Hot Commissioning)?
<input type="radio"/>	Has the actual equipment/process successfully operated in the operational environment (Hot Commissioning)?
<input type="radio"/>	Has the actual equipment/process successfully operated in the relevant operational environment(Cold Commissioning)?
<input type="radio"/>	Has a prototypic equipment/process system demonstrated in a relevant environment (Cold Pilot Plant)?
<input type="radio"/>	Has bench scale equipment/process testing been demonstrated in a relevant environment?
<input type="radio"/>	Has laboratory scale testing of similar equipment systems been completed in a simulated environment?
<input type="radio"/>	Has equipment and process analysis and proof of concept been demonstrated in a simulated environment?
<input type="radio"/>	Has an equipment and process concept been formulated?
<input type="radio"/>	Have the basic process technology process principles been observed and reported?
<input type="radio"/>	None of the above



TRL Calculator-Level 1 Questions

H/SW	Ques	Do you want to assume completion of TRL 1?			TRL 1 (Check all that apply or use slider for % complete)
		Both	Catgry	% Complete	
B	T	◀	▶	<input type="checkbox"/>	"Back of envelope" environment
B	T	◀	▶	<input type="checkbox"/>	Physical laws and assumptions used in new technologies defined
S	T	◀	▶	<input type="checkbox"/>	Have some concept in mind for software that may be realizable in software
S	T	◀	▶	<input type="checkbox"/>	Know what software needs to do in general terms
B	T	◀	▶	<input type="checkbox"/>	Paper studies confirm basic principles
S	T	◀	▶	<input type="checkbox"/>	Mathematical formulations of concepts that might be realizable in software
S	T	◀	▶	<input type="checkbox"/>	Have an idea that captures the basic principles of a possible algorithm
B	P	◀	▶	<input type="checkbox"/>	Initial scientific observations reported in journals/conference proceedings/technical reports
B	T	◀	▶	<input type="checkbox"/>	Basic scientific principles observed
B	P	◀	▶	<input type="checkbox"/>	Know who cares about technology, e.g., sponsor, money source
B	T	◀	▶	<input type="checkbox"/>	Research hypothesis formulated
B	P	◀	▶	<input type="checkbox"/>	Know who will perform research and where it will be done



TRL Calculator-Level 2 Questions

H/SW Both	Ques Catgry	Do you want to assume completion of TRL 2?		TRL 2 (Check all that apply or use slider for % complete)
		% Complete		
B	P	◀	▶	<input type="checkbox"/> Customer identified
B	T	◀	▶	<input type="checkbox"/> Potential system or component application(s) have been identified
B	T	◀	▶	<input type="checkbox"/> Paper studies show that application is feasible
B	P	◀	▶	<input type="checkbox"/> Know what program the technology will support
B	T	◀	▶	<input type="checkbox"/> An apparent theoretical or empirical design solution identified
H	T	◀	▶	<input type="checkbox"/> Basic elements of technology have been identified
B	T	◀	▶	<input type="checkbox"/> Desktop environment
H	T	◀	▶	<input type="checkbox"/> Components of technology have been partially characterized
H	T	◀	▶	<input type="checkbox"/> Performance predictions made for each element
B	P	◀	▶	<input type="checkbox"/> Customer expresses interest in application
S	T	◀	▶	<input type="checkbox"/> Some coding to confirm basic principles
B	T	◀	▶	<input type="checkbox"/> Initial analysis shows what major functions need to be done
H	T	◀	▶	<input type="checkbox"/> Modeling & Simulation only used to verify physical principles
B	P	◀	▶	<input type="checkbox"/> System architecture defined in terms of major functions to be performed
S	T	◀	▶	<input type="checkbox"/> Experiments performed with synthetic data
B	P	◀	▶	<input type="checkbox"/> Requirement tracking system defined to manage requirements creep
B	T	◀	▶	<input type="checkbox"/> Rigorous analytical studies confirm basic principles
B	P	◀	▶	<input type="checkbox"/> Analytical studies reported in scientific journals/conference proceedings/technical reports
B	T	◀	▶	<input type="checkbox"/> Individual parts of the technology work (No real attempt at integration)
S	T	◀	▶	<input type="checkbox"/> Know what hardware software will be hosted on
B	T	◀	▶	<input type="checkbox"/> Know what output devices are available
B	P	◀	▶	<input type="checkbox"/> Preliminary strategy to obtain TRL Level 6 developed (e.g scope, schedule, cost)
B	P	◀	▶	<input type="checkbox"/> Know capabilities and limitations of researchers and research facilities
B	T	◀	▶	<input type="checkbox"/> Know what experiments are required (research approach)
B	P	◀	▶	<input type="checkbox"/> Qualitative idea of risk areas (cost, schedule, performance)



TRL Calculator-Level 3 Questions

H/SW Both	Ques Catgry	Do you want to assume completion of TRL 3?		TRL 3 (Check all that apply or use slider for % complete)
		% Complete		
B	T	◀	▶	<input type="checkbox"/> Academic environment
H	T	◀	▶	<input type="checkbox"/> Predictions of elements of technology capability validated by Analytical Studies
B	P	◀	▶	<input type="checkbox"/> The basic science has been validated at the laboratory scale
H	T	◀	▶	<input type="checkbox"/> Science known to extent that mathematical and/or computer models and simulations are possible
H	P	◀	▶	<input type="checkbox"/> Preliminary system performance characteristics and measures have been identified and estimated
S	T	◀	▶	<input type="checkbox"/> Outline of software algorithms available
H	T	◀	▶	<input type="checkbox"/> Predictions of elements of technology capability validated by Modeling and Simulation (M&S)
S	T	◀	▶	<input type="checkbox"/> Preliminary coding verifies that software can satisfy an operational need
H	M	◀	▶	<input type="checkbox"/> No system components, just basic laboratory research equipment to verify physical principles
B	T	◀	▶	<input type="checkbox"/> Laboratory experiments verify feasibility of application
H	T	◀	▶	<input type="checkbox"/> Predictions of elements of technology capability validated by Laboratory Experiments
B	P	◀	▶	<input type="checkbox"/> Customer representative identified to work with development team
B	P	◀	▶	<input type="checkbox"/> Customer participates in requirements generation
B	T	◀	▶	<input type="checkbox"/> Cross technology effects (if any) have begun to be identified
H	M	◀	▶	<input type="checkbox"/> Design techniques have been identified/developed
B	T	◀	▶	<input type="checkbox"/> Paper studies indicate that system components ought to work together
B	P	◀	▶	<input type="checkbox"/> Customer identifies transition window(s) of opportunity
B	T	◀	▶	<input type="checkbox"/> Performance metrics for the system are established
B	P	◀	▶	<input type="checkbox"/> Scaling studies have been started
S	T	◀	▶	<input type="checkbox"/> Experiments carried out with small representative data sets
S	T	◀	▶	<input type="checkbox"/> Algorithms run on surrogate processor in a laboratory environment



TRL Calculator-Level 3 Questions (continued)

H/SW	Ques	Do you want to assume completion of TRL 3?		TRL 3 (Check all that apply or use slider for % complete)									
Both	Catgry	% Complete											
H	M	◀	▶	<input type="checkbox"/>	Current manufacturability concepts assessed								
S	T	◀	▶	<input type="checkbox"/>	Know what software is presently available that does similar task (100% = Inventory completed)								
S	T	◀	▶	<input type="checkbox"/>	Existing software examined for possible reuse								
H	M	◀	▶	<input type="checkbox"/>	Sources of key components for laboratory testing identified								
S	T	◀	▶	<input type="checkbox"/>	Know limitations of presently available software (Analysis of current software completed)								
B	T	◀	▶	<input type="checkbox"/>	Scientific feasibility fully demonstrated								
B	T	◀	▶	<input type="checkbox"/>	Analysis of present state of the art shows that technology fills a need								
B	P	◀	▶	<input type="checkbox"/>	Risk areas identified in general terms								
B	P	◀	▶	<input type="checkbox"/>	Risk mitigation strategies identified								
B	P	◀	▶	<input type="checkbox"/>	Rudimentary best value analysis performed for operations								
B	P	◀	▶	<input type="checkbox"/>	The individual system components have been tested at the laboratory scale								



TRL Calculator-Level 4 Questions

H/SW Both	Ques Catgry	% Complete	TRL 4 (Check all that apply or use slider for % complete)	
			<input type="checkbox"/>	Cross technology issues (if any) have been fully identified
H	M	◀ ▶	<input type="checkbox"/>	Laboratory components tested are surrogates for system components
H	T	◀ ▶	<input type="checkbox"/>	Individual components tested in laboratory/by supplier (contractor's component acceptance testing)
B	T	◀ ▶	<input type="checkbox"/>	Subsystems composed of multiple components tested at lab scale using simulants
H	T	◀ ▶	<input type="checkbox"/>	M&S used to simulate some components and interfaces between components
S	T	◀ ▶	<input type="checkbox"/>	Formal system architecture development begins
B	P	◀ ▶	<input type="checkbox"/>	Customer publishes requirements document
B	T	◀ ▶	<input type="checkbox"/>	Overall system requirements for end user's application are known
B	P	◀ ▶	<input type="checkbox"/>	System performance metrics have been established
S	T	◀ ▶	<input type="checkbox"/>	Analysis provides detailed knowledge of specific functions software needs to perform
B	P	◀ ▶	<input type="checkbox"/>	Laboratory requirements derived from system requirements are established
H	M	◀ ▶	<input type="checkbox"/>	Available components assembled into laboratory scale system
H	T	◀ ▶	<input type="checkbox"/>	Laboratory experiments with available components show that they work together (lab kludge)
S	T	◀ ▶	<input type="checkbox"/>	Requirements for each system function established
S	T	◀ ▶	<input type="checkbox"/>	Algorithms converted to pseudocode
S	T	◀ ▶	<input type="checkbox"/>	Analysis of data requirements and formats completed
S	T	◀ ▶	<input type="checkbox"/>	Stand-alone modules follow preliminary system architecture plan
H	T	◀ ▶	<input type="checkbox"/>	Analysis completed to establish component compatibility
S	M	◀ ▶	<input type="checkbox"/>	Designs verified through formal inspection process
B	P	◀ ▶	<input type="checkbox"/>	Science and Technology exit criteria established
B	T	◀ ▶	<input type="checkbox"/>	Technology demonstrates basic functionality in simulated environment
S	P	◀ ▶	<input type="checkbox"/>	Able to estimate software program size in lines of code and/or function points
H	M	◀ ▶	<input type="checkbox"/>	Scalable technology prototypes have been produced
B	P	◀ ▶	<input type="checkbox"/>	Draft conceptual designs have been documented
H	M	◀ ▶	<input type="checkbox"/>	Equipment scaleup relationships are understood/accounted for in technology development program



TRL Calculator-Level 4 Questions (continued)

H/SW	Ques	% Complete	TRL 4 (Check all that apply or use slider for % complete)	
Both	Catgry		◀	▶
B	T	<input type="checkbox"/>	Controlled laboratory environment used in testing	
B	P	<input type="checkbox"/>	Initial cost drivers identified	
S	T	<input type="checkbox"/>	Experiments with full scale problems and representative data sets	
B	M	<input type="checkbox"/>	Integration studies have been started	
B	P	<input type="checkbox"/>	Formal risk management program initiated	
S	T	<input type="checkbox"/>	Individual functions or modules demonstrated in a laboratory environment	
H	M	<input type="checkbox"/>	Key manufacturing processes for equipment systems identified	
B	P	<input type="checkbox"/>	Scaling documents and designs of technology have been completed	
S	T	<input type="checkbox"/>	Some ad hoc integration of functions or modules demonstrates that they will work together	
H	M	<input type="checkbox"/>	Key manufacturing processes assessed in laboratory	
B	P	<input type="checkbox"/>	Functional work breakdown structure developed	
B	T	<input type="checkbox"/>	Low fidelity technology "system" integration and engineering completed in a lab environment	
H	M	<input type="checkbox"/>	Mitigation strategies identified to address manufacturability / producibility shortfalls	
B	P	<input type="checkbox"/>	Technology availability dates established	
B	T	<input type="checkbox"/>	Functional work breakdown structure developed	



TRL Calculator-Level 5 Questions

H/SW Both	Ques Catgry	% Complete	TRL 5 (Check all that apply or use sliders)	
B	T	◀ ▶	<input type="checkbox"/>	Cross technology effects (if any) have been fully identified
B	T	◀ ▶	<input type="checkbox"/>	Plant size components available for testing
B	T	◀ ▶	<input type="checkbox"/>	System interface requirements known
B	P	◀ ▶	<input type="checkbox"/>	System requirements flow down through work breakdown structure (systems engineering begins)
S	T	◀ ▶	<input type="checkbox"/>	System software architecture established
B	T	◀ ▶	<input type="checkbox"/>	Requirements for technology verification established
S	T	◀ ▶	<input type="checkbox"/>	External process/equipment interfaces described as to source, structure, and requirements
S	T	◀ ▶	<input type="checkbox"/>	Analysis of internal system interface requirements completed
B	T	◀ ▶	<input type="checkbox"/>	Lab scale similar system tested with limited range of actual wastes
B	T	◀ ▶	<input type="checkbox"/>	Interfaces between components/subsystems are realistic (benchtop with realistic interfaces)
H	M	◀ ▶	<input type="checkbox"/>	Significant engineering and design changes
S	T	◀ ▶	<input type="checkbox"/>	Coding of individual functions/modules completed
H	M	◀ ▶	<input type="checkbox"/>	Prototypes have been created
H	M	◀ ▶	<input type="checkbox"/>	Tooling and machines demonstrated in lab
B	T	◀ ▶	<input type="checkbox"/>	High fidelity lab integration of system completed, ready for test in relevant environments
H	M	◀ ▶	<input type="checkbox"/>	Design techniques have been defined to the point where largest problems defined
H	P	◀ ▶	<input type="checkbox"/>	Lab scale similar system tested with range of simulations
H	T	◀ ▶	<input type="checkbox"/>	Fidelity of system mock-up improves from laboratory to benchscale testing
B	M	◀ ▶	<input type="checkbox"/>	Availability and reliability target levels not yet established
H	M	◀ ▶	<input type="checkbox"/>	Some special purpose components combined with available laboratory components



TRL Calculator-Level 5 Questions (continued)

H/SW	Ques						
Both	Catgry						
TRL 5 (Check all that apply or use sliders)							
H	P	◀	▶	<input type="checkbox"/>	Three dimensional drawings and P&IDs diagrams have been prepared		
B	T	◀	▶	<input type="checkbox"/>	Laboratory environment for testing modified to approximate operational environment		
B	T	◀	▶	<input type="checkbox"/>	Component integration issues and requirements identified		
H	P	◀	▶	<input type="checkbox"/>	Detailed design drawings have been completed		
B	T	◀	▶	<input type="checkbox"/>	Requirements definition with performance thresholds and objectives established		
S	T	◀	▶	<input type="checkbox"/>	Algorithms run on processor with characteristics representative of target environment		
B	T	◀	▶	<input type="checkbox"/>	Preliminary technology feasibility engineering report completed		
B	T	◀	▶	<input type="checkbox"/>	Integration of modules/functions demonstrated in a laboratory environment		
B	T	◀	▶	<input type="checkbox"/>	Formal inspection of all modules/components completed as part of configuration management		
B	P	◀	▶	<input type="checkbox"/>	Configuration management plan in place		
B	P	◀	▶	<input type="checkbox"/>	Risk management plan documented		
S	T	◀	▶	<input type="checkbox"/>	Functions integrated into modules		
B	P	◀	▶	<input type="checkbox"/>	Configuration management plan in place		
S	T	◀	▶	<input type="checkbox"/>	Individual functions tested to verify that they work		
S	T	◀	▶	<input type="checkbox"/>	Individual modules and functions tested for bugs		
S	T	◀	▶	<input type="checkbox"/>	Integration of modules/functions demonstrated in a laboratory environment		
S	P	◀	▶	<input type="checkbox"/>	Formal inspection of all modules/components completed as part of configuration management		
B	P	◀	▶	<input type="checkbox"/>	Configuration management plan documented		
B	T	◀	▶	<input type="checkbox"/>	Risk management plan documented		
B	T	◀	▶	<input type="checkbox"/>	Functions integrated into modules		
H	P	◀	▶	<input type="checkbox"/>	Individual process and equipment functions tested to verify that they work		



TRL Calculator-Level 6 Questions

H/SW Both	Ques Catgry	% Complete	TRL 6 (Check all that apply or use sliders)	
B	T	◀ ▶	<input type="checkbox"/>	Cross technology issue measurement and performance characteristic validations completed
H	M	◀ ▶	<input type="checkbox"/>	Availability (reliability, maintainability) levels established
B	M	◀ ▶	<input type="checkbox"/>	Frequent design changes occur
H	P	◀ ▶	<input type="checkbox"/>	Draft design drawings are nearly complete
B	T	◀ ▶	<input type="checkbox"/>	Operating environment for eventual system known
B	P	◀ ▶	<input type="checkbox"/>	Collection of actual maintainability, reliability, and supportability data has been started
B	P	◀ ▶	<input type="checkbox"/>	Design to cost goals identified
B	T	◀ ▶	<input type="checkbox"/>	Engineering scale similar system tested with a range of simulants
B	T	◀ ▶	<input type="checkbox"/>	Modeling and Simulation used to simulate system performance in an operational environment
B	P	◀ ▶	<input type="checkbox"/>	Plan for demonstration of prototypical equipment and process testing completed, results verify design
H	T	◀ ▶	<input type="checkbox"/>	Operating limits determined using engineering scale system
B	T	◀ ▶	<input type="checkbox"/>	Representative model / prototype tested in high-fidelity lab / simulated operational environment
B	P	◀ ▶	<input type="checkbox"/>	Formal requirements document available
B	P	◀ ▶	<input type="checkbox"/>	Off-normal operating responses determined for engineering scale system
B	T	◀ ▶	<input type="checkbox"/>	System technical interfaces defined
B	T	◀ ▶	<input type="checkbox"/>	Component integration demonstrated at an engineering scale
B	P	◀ ▶	<input type="checkbox"/>	Scaling issues that remain are identified and supporting analysis is complete
B	P	◀ ▶	<input type="checkbox"/>	Analysis of project timing ensures technology will be available when required
S	T	◀ ▶	<input type="checkbox"/>	Analysis of database structures and interfaces completed
B	P	◀ ▶	<input type="checkbox"/>	Have begun to establish an interface control process
B	P	◀ ▶	<input type="checkbox"/>	Acquisition program milestones established
H	M	◀ ▶	<input type="checkbox"/>	Critical manufacturing processes prototyped
H	M	◀ ▶	<input type="checkbox"/>	Most pre-production hardware is available



TRL Calculator-Level 6 Questions (continued)

H/SW Both	Ques Catgry	% Complete	TRL 6 (Check all that apply or use sliders)	
B	T	◀ ▶	<input type="checkbox"/>	Engineering feasibility fully demonstrated
S	T	◀ ▶	<input type="checkbox"/>	Prototype implementation includes functionality to handle large scale realistic problems
S	T	◀ ▶	<input type="checkbox"/>	Algorithms partially integrated with existing hardware / software systems
H	M	◀ ▶	<input type="checkbox"/>	Materials, process, design, and integration methods have been employed
S	T	◀ ▶	<input type="checkbox"/>	Individual modules tested to verify that the module components (functions) work together
B	P	◀ ▶	<input type="checkbox"/>	Technology "system" specification complete
H	M	◀ ▶	<input type="checkbox"/>	Components are functionally compatible with operational system
S	T	◀ ▶	<input type="checkbox"/>	Representative software system or prototype demonstrated in a laboratory environment
B	T	◀ ▶	<input type="checkbox"/>	Engineering scale system is high-fidelity functional prototype of operational system
B	P	◀ ▶	<input type="checkbox"/>	Formal configuration management program defined to control change process
B	M	◀ ▶	<input type="checkbox"/>	Integration demonstrations have been completed
B	P	◀ ▶	<input type="checkbox"/>	Final Technical Report on Technology completed
B	T	◀ ▶	<input type="checkbox"/>	Processing issues have been identified and major ones have been resolved
S	T	◀ ▶	<input type="checkbox"/>	Limited software documentation available
S	P	◀ ▶	<input type="checkbox"/>	Verification, Validation and Accreditation (VV&A) initiated
H	M	◀ ▶	<input type="checkbox"/>	Process and tooling are mature
H	M	◀ ▶	<input type="checkbox"/>	Production demonstrations are complete
B	T	◀ ▶	<input type="checkbox"/>	"Alpha" version software has been released
B	T	◀ ▶	<input type="checkbox"/>	Engineering feasibility fully demonstrated
B	P	◀ ▶	<input type="checkbox"/>	Technology ready for detailed design implementation